T-1
Mechanics of Materials & Equation-of-State

Universality in the High-Pressure Hugoniot

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Data for the low-pressure shock Hugoniot is available for a large number of materials and the accompanying understanding of the physics is also in hand. Above 5 Mbar the number of data points is, relatively speaking, quite small with all useful data coming from nuclear driven experiments. An amalgamation of the high pressure information into a coherent, simple picture has been lacking.

Using the Hugoniot jump relations, which represent the conservation of mass, energy, and momentum through the shock process, one can derive

$$2S - 2 - \gamma = \frac{C}{SU_p}\left[1 - 3S + \frac{B_s}{P} - \frac{C}{U_p}\right].$$

The independent variable here is the shock particle velocity U_p. The thermodynamics enters through the isentropic bulk modulus B_s, the pressure P, and the Grüneisen constant

$$\gamma \equiv \frac{1}{\rho}\frac{\partial P}{\partial E}\bigg)_\rho .$$

All these are functions of U_p. The dependent variables are not the shock velocity U_s but instead are C and S. These are the intercept at $U_p = 0$ and slope of the tangent line to the $U_s - U_p$ Hugoniot, respectively. One is doing a Legendre transform. For strong shocks the right of the equation is small (U_p is large) thus implying that the slope of the $U_s - U_p$ curve is

$$S = 1 + \gamma / 2.$$

For regions of the Hugoniot above 5 Mbar one can easily argue that ionization is the dominate physics of the equation of state and determines the behavior of γ. In particular it is expected that the energy sink of ionization will pull γ below the ideal gas value of 2/3. In addition a negative γ would be anomalous. Thus $\gamma = 0.4 \pm 0.1$ is a quite reasonable estimate throughout ionization; a large region of the Hugoniot. This implies that $S = 1.2 \pm 0.05$ over a large range of U_p, from say *5 km/s* up to a few hundred *km/s*. The slope is very constant, the $U_s - U_p$ Hugoniot is linear.

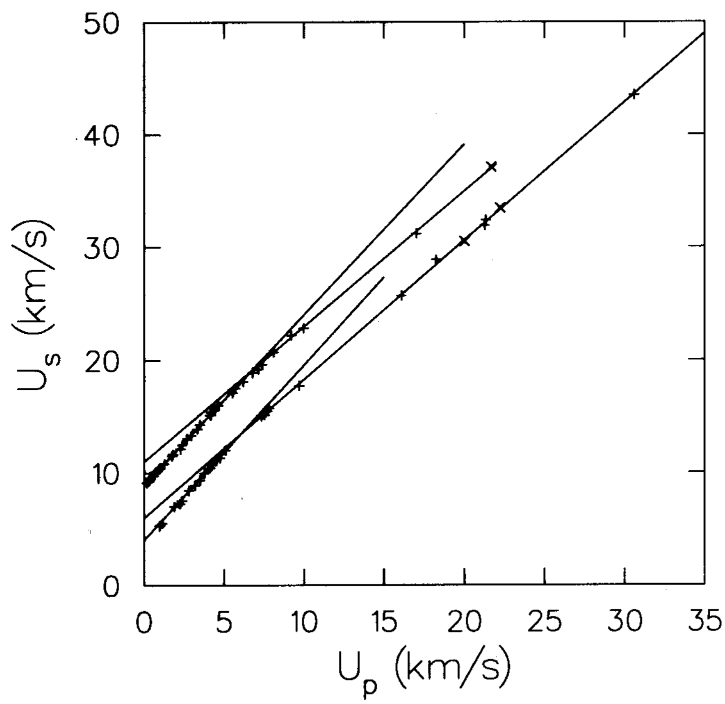

Figure 1: Fe and Cu Hugoniot data. We see clearly the linearity of the upper data and a well-defined break. The Cu data and curves have been shifted upwards.

Figures 1 and 2 show shock data for six elements Bi, Fe, Cu, Sn, Ar, and Xe. All exhibit the expected very linear $U_s - U_p$ curve for low pressure. The higher slope straight lines are fits to the low data. But we also see a break to a higher pressure region with very linear behavior. All these slopes fall between 1.14 and 1.22. This is all quite in line with electron ionization breaking the low-pressure Hugoniot over to another region of constant slope.

This new picture of the high-pressure Hugoniot gives us increased understanding, the capability to make estimates without data, and decreases the need for more high-pressure data.

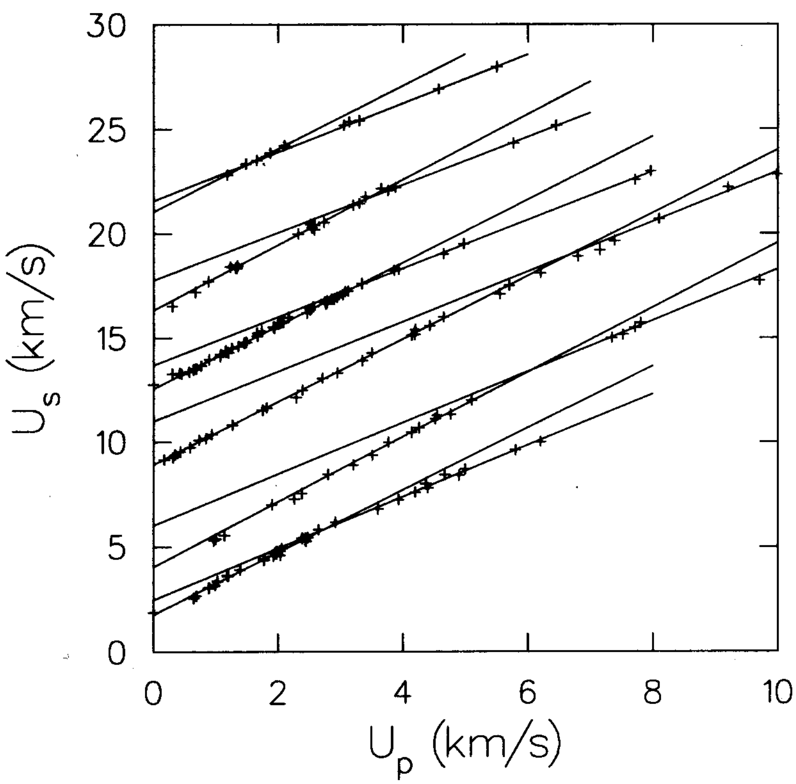

Figure 2: Bi, Fe, Cu, Sn, Ar, and Xe Hugoniot data from bottom to top. Shifts have been introduced to avoid overlaps.

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